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THE EFFECT OF INHALATION OF LOW OXYGEN CONCENTRATION  
(10.5% O<sub>2</sub> IN N<sub>2</sub>) OVER A PERIOD OF 33 MINUTES ON  
RESPIRATION, PULSE RATE, ARTERIAL OXYGEN SATURATION  
(OXIMETER) AND OXYGEN UPTAKE

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K. E. Schaefer and H. J. Alvis, The effect of inhalation of low oxygen concentration (10.5% O<sub>2</sub> in N<sub>2</sub>) over a period of 33 minutes on respiration, pulse rate, arterial oxygen saturation (oximeter) and oxygen uptake. MRL Report No. 175, 10, 76-97, 1951.

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## OPERATIONAL APPLICATION

This work is part of a study to determine oxygen consumption and carbon dioxide excretion at different partial pressure of oxygen, undertaken to better the understanding of oxygen toxicity. Results provide an answer to the long-discussed question as to (1) whether oxygen consumption is decreased at low partial pressures, and if so, (2) whether the decrease is commensurate with the decrease of partial pressure. There was found a transient initial decrease in oxygen uptake correlated with the decreased partial pressure of oxygen (altitude), following which there was observed either an increase in oxygen consumption, in the case of a group of sedentary technicians, or development of a large oxygen debt among a group of "skin divers". Data revealed two distinct patterns of response to low oxygen: a high ventilation response in sedentary workers and a low ventilation response in "skin divers". On the basis of observed varying reactions to low oxygen, contrary reports in the literature can be explained.

This study appears to provide a functional test of instructors at the Escape Training Tank. Four or five instructors at the Escape Training Tank who volunteered as subjects in these experiments belonged to the low ventilation group. A Medical Research Assistant, who was in excellent physical condition, also showed a low ventilation response. The high ventilation group consisted of five laboratory personnel and one instructor at the Escape Training Tank. Since exposure to low oxygen is one of the important stresses of extended breathholding, as encountered by instructors at the Escape Training Tank, the findings suggest that there might be a state of acclimatization to the stress of skin diving or breathholding. The efficiency of the instructors as skin divers was related to the ability to accept a large oxygen debt and make better utilization of available oxygen with a minimal increase of pulmonary ventilation.

## ABSTRACT

Eleven subjects were studied during 33 minute periods while breathing air, 10.5% O<sub>2</sub> in N<sub>2</sub> and again breathing air. The average response to 10.5% O<sub>2</sub> was an increase in respiratory volume due to an increased tidal volume, a decrease in arterial oxygen saturation and an increase of the pulse rate of the same order of magnitude as the increase in respiratory minute volume. The average oxygen consumption showed a significant initial decrease and then returned to essentially basal values followed by a marked increase in the first part of the recovery period. The CO<sub>2</sub> excretion was significantly increased throughout the exposure period and significantly decreased after the 11th minute of the recovery period. The respiratory quotient was increased throughout the exposure period and decreased throughout the recovery period.

A group of five subjects was differentiated by their low respiratory minute volume response to 10.5% O<sub>2</sub> and their ability to make better utilization of available oxygen and to accept a large oxygen debt. An attempt was made to separate the decrease in O<sub>2</sub> uptake due to decrease in hemoglobin oxygen saturation from the oxygen debt.

## INTRODUCTION

The experiments described here were part of a study to determine oxygen consumption and carbon dioxide excretion at different partial pressures of oxygen. The reported experimental findings dealing with this subject are far from consistent. Gesell, et al (1) found in the animal during acute hypoxia an increase in oxygen uptake after a short transient decrease. For human subjects the data in the literature show considerable variation. Benzinger (2), Ruehl and Kuehn (3) observed increased oxygen uptake, whereas Opitz and Tilmann (4) found reduced oxygen uptake. Jouck (5) confirmed, in general, with a limited number of human subjects, the curve of oxygen uptake during acute hypoxia which Gesell had established in animal experiments. Cook (6) found a 7 to 15% decrease in oxygen consumption at 30,000 feet. Nims and Olmsted (7) in measurements on ten subjects for 30 minutes, preflight, at 30,000 feet, and post-flight, were unable to confirm the results of Cook. The inconsistency of the results of these studies may be explained on the basis of different durations of the experimental periods and on the influence of high room temperature and humidity in the experiments of Nims and Olmsted. An initial decrease in oxygen uptake, which is most frequently reported, is to be expected from the initial decrease of the  $pO_2$  alveolar- $pO_2$  venous gradient upon breathing a gas with a lower partial pressure of oxygen and the reduction in oxygen uptake of the blood due to the lower arterial oxygen saturation. We were interested to determine the duration and extent of the diminished oxygen uptake and the subsequent increased oxygen uptake. The experiments should furnish us also more complete data concerning the average physiological response to hypoxia under basal conditions and constant room temperature in the range of 23-25°C.

## MATERIALS AND METHODS

Our subjects comprised eleven naval and civil service personnel with ages ranging from 27 to 40. Subjects I through V were

laboratory personnel, ages 35 to 40, engaged in sedentary activities. Subjects VI through X, ages 27 to 37, were instructors at the Escape Training Tank at the Submarine Base, New London, Conn. These men engaged in "skin" diving involving repeated breathholding and exposures to submersion in water or to air pressures as high as 4 atm. abs. almost daily, five days a week. Subject XI was a hospital corpsman, a Medical Research Assistant of the laboratory group, a qualified first class deep sea diver in excellent physical condition but who during this period was not engaged in diving work. Physical data for the subjects are shown in Table 1.

Each subject reported in the morning under basal conditions (14 hours without food) and rested on a bed for 45 minutes before the experiment began. Comfort was assured during the experimental period. The subject was required to breathe, while in the supine position, from an open spirometer system through a flanged mouth-piece for (a) an initial period of 33 minutes on room air, followed by (b) 33 minutes on a mixture of 10.5% oxygen in nitrogen, and finally (c) a recovery period of 33 minutes on room air.

Two trials were conducted on each subject; the time interval between trials was several months. As to the apparatus and gases used, the gas mixtures were prepared in 1.6 cu. ft. gas bottles which were connected for use to a 5-liter spirometer. From this spirometer the gases were inhaled through a demand valve and the respiratory rate recorded. Four Douglas bags were attached to a manifold leading from the respiratory valve and the expired gases were measured during the following time periods: From 0'15"-5'15", 5'30"-11'30", 11'45"-17'45", 18-23', and 23'15"-33'15". The expiratory limb of the system, including the valves of the Douglas bags, required 15 seconds to flush out the dead space between samples.

The respiratory valve was equipped with an automatic alveolar gas sampling device (Rahn, et al (8)). Gas collected at the end of a normal exhalation was accumulated over a series of expirations during the last three minutes of exposure to air or low oxygen and analyzed with the Haldane apparatus. The expired gas collected in Douglas bags was corrected for volume and content of the portion

removed by the automatic sampling device. Measurements on the following physiological variables were obtained:

- a. Pulse count, radial, 2 minute intervals.
- b. Ventilation volume by one minute interval reading of the spirometer and for 5, 6 and 10 minute periods by measuring the contents of the Douglas bags.
- c. Arterial oxygen saturation, oximeter (Millikan-Coleman modification), 2 minute interval.
- d. Respiratory rate, continuously recorded.
- e. Respiratory tidal volume, computed from (b) and (d) after correcting ventilation volume to B.T.P.S. (Body Temperature and Pressure, Saturated).
- f. Alveolar gas samples at the end of 33 minute periods of room air, of 10.5% O<sub>2</sub> and again of room air.
- g. Inspired CO<sub>2</sub> and O<sub>2</sub> concentrations at the end of 30 minutes by sampling from the mouthpiece.
- h. Expired CO<sub>2</sub> and O<sub>2</sub> concentrations from Douglas bags at intervals of 0'15"-5'15", 5'30"-11'30", 11'45"-17'45", 18-23', 23'15"-33'15" (15 second intervals for flushing manifold).
- i. Blood pressure at 5 minute intervals during exposure to low O<sub>2</sub> (in the second trial only).

The volume of the expired air in the Douglas bags was measured in a spirometer. Gas samples were taken from the Douglas bags in glass tonometers over mercury, flushing the sample twice after first rinsing the nitrometer tube connector of the bag. Gas analyses in duplicate were made with the Haldane apparatus. Inspired air volume was corrected for differences in nitrogen concentrations between expired and inspired air.

In the first five experiments of the first trial, the expired gases were measured with a Tissot spirometer at minute intervals. These data were converted to values which could be compared with the values for the longer time periods used in the Douglas bag experiments. Difficulty in adequately flushing the spirometer prevented the collection of oxygen consumption data throughout the whole exposure period for five subjects in the first trial series. The remaining six subjects were tested in the first trial with the Douglas bag technique. The data were in every way comparable to that of the second

trial. Consequently, the data for oxygen consumption are taken from the second trial.

## RESULTS

### 1. The Average Physiological Response to 10.5% Oxygen in Nitrogen for 11 Subjects.

#### a. Respiration and Circulation (Tables 2 and 3).

Tables 2-A and 2-B show the average respiratory and circulatory changes produced by breathing 10.5% oxygen for a period of 33 minutes in two trials. An inspection of the data in section A of these tables reveals in both trials a significant increase in respiratory minute volume. This is due to an increase in tidal volume (section C). The respiratory rate shows no significant change (section B). There was a significant increase in pulse rate and fall in oxygen saturation in both trials, as will be seen in sections D and E of the tables. In the second trial systolic blood pressure determinations were added to the observations. A significant increase in systolic blood pressure from 0-11 minutes and a significant decrease from the 23d minute of the exposure over into the 0-5 minute portion of the recovery period were noted. During the recovery period of the first trial the respiratory minute volume, respiratory rate, oxygen saturation and pulse rate showed a definite counter movement to that change which occurred during the stress of hypoxia (see sections A, B, D, E). Early in the recovery period the respiratory minute volume and respiratory rate fell below the initial resting values. Later, the pulse rate decreased below and oxygen saturation reached a level above their respective initial values. During the second trial the results showed the same trends but the values were spread over a wider range. The average respiratory minute volume and average pulse rate for both trials are presented in Table 3, expressed in percentage of basic values for each time interval during the exposure to 10.5% oxygen and the subsequent recovery period while breathing air.

Measures of test-retest reliability were obtained by correlating the average respiratory minute volume for a specific time interval of the first and second trials ( $r = .763$ ). Similarly, the reliability coefficient for the average pulse rate was  $r = .74$ . These are fairly high for physiological data.

b. Oxygen Consumption and Carbon Dioxide Excretion (Table 4).

Average values of oxygen consumption are less by a statistically significant amount during the first two time periods, 0-5 and 5-11 minutes, of the exposure to 10.5% oxygen. However, during the subsequent periods (11-33 minutes) there were no significant deviations from basic values. In the recovery period, while breathing air, there was a markedly greater oxygen uptake during the first five minutes. The periods 5-33 minutes showed no statistically significant rise over basic values. In order to make a comparison between this and other reports, both the observed and the percentage values are given in Table 4. Carbon dioxide excretion was greater by a statistically significant amount in every time period during the exposure to 10.5% oxygen (Table 4). During the recovery period the absolute values of carbon dioxide excretion were less. On a percentage basis the diminution was statistically significant during all time periods other than the 5-11 minute interval in the recovery phase.

c. Respiratory Quotient (Table 5).

The average respiratory quotient of the expired air during the basic state prior to exposure was .84 which agrees well with basic values in the literature (9). During each time interval of the exposure to 10.5% oxygen the respiratory quotient was significantly greater than .84. During each time interval of the recovery phase the respiratory quotient was significantly less than .84. It is of interest to note that in neither instance did the respiratory quotient return to the basic value within the 33 minute period.

d. Alveolar Carbon Dioxide and Oxygen Tensions (Table 6).

Values of alveolar gas tensions at the end of 33 minutes exposure to air and low oxygen are given in Table 6. The alveolar

air samples were collected over short time periods during the course of the experiments. The resulting data probably furnish a gross approximation of what would be obtained had the collection periods been longer. Considering the differences between the Haldane-Priestly method and the automatic sampling method these data well fit the comparable curves in the Handbook of Respiratory Data (10).

## 2. Differences in the Physiological Response to Low Oxygen.

### a. Respiratory Minute Volume (Table 7).

Inspection of the data for respiratory minute volume during the exposure period for all subjects for both trials permitted the differentiation of the subjects into a high and low ventilation group. Each of the six subjects thus placed in Group A showed in each trial in each time period a ventilatory response in the range of 140-184% (basic values = 100%). Each of the five subjects in Group B showed in each trial in each time period a ventilatory response in the range of 118-135%. As shown in Table 7, the respiratory minute volume during exposure to low oxygen is significantly different between the two groups, from the 18th to 33d minute in the first trial and from the 11th to the 33d minute in the second trial. Comparing the first and second trials for each group separately, it can be seen that the respiratory response to low oxygen is very consistent. The test-retest reliability for Group A was  $r = .75$ ; for Group B,  $r = .81$ . Although the respiratory minute volume showed a significant difference between the two groups, no such difference could be shown for either the tidal volume or the respiratory rate because of the individual variations.

### b. Oxygen Removal and Arterial Oxygen Saturation (Table 8).

We should expect to find in the low ventilation group a larger oxygen removal from the inspired air into the blood, and a lower alveolar  $pO_2$  and higher alveolar  $pCO_2$ , and a lower arterial oxygen saturation. As shown in Table 8, the maximum value of oxygen removal in any time period was larger in the low ventilation group, while in three out of four cases\* of this group the maximum

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\* During the run with the 5th subject of this group the oximeter failed.

drop in arterial oxygen saturation reached lower levels than the high ventilation group. The differences in the first trial were significant, while the differences in the second were not significant. In the first trial at the end of 33 minutes exposure to 10.5% O<sub>2</sub>, the mean arterial oxygen saturation of the low ventilation group was  $63.8 \pm 4.1$  compared with  $74.7 \pm 2.4$  of the high ventilation group (significantly different at the .01 level). In the second trial the values were 68.8 and 74.2 (not significantly different).

c. Alveolar pCO<sub>2</sub> and pO<sub>2</sub>.

The alveolar air samples did not show a significant difference between the two groups as had been anticipated, a finding which may have been obscured by our inability to employ continuous recording of alveolar air content.

d. Oxygen Debt and Compensatory Uptake Resulting from Exposure to 10.5% O<sub>2</sub> in N<sub>2</sub> (Table 9).

The oxygen debt was calculated from determination of the difference in oxygen uptake while breathing 21% and 10.5% O<sub>2</sub>. The oxygen debt accepted during 33 minutes exposure to 10.5% oxygen was significantly greater for the low ventilation group (Table 9). The oxygen balance at the end of the exposure period was in deficit by a significantly greater amount for Group B (low ventilation). The final oxygen balance at the end of the recovery period was negative in two cases of the low ventilation group, or showed relatively small positive values compared with the high ventilation group. If subject 5 (case of pulmonary emphysema\*) is excluded from the high ventilation group, the difference in final oxygen balance between the two groups becomes significant.

e. Blood Data for Eleven Subjects (Table 10).

Red blood cell counts, hemoglobin and hematocrit values of the eleven subjects are given in Table 10. In only one case an exceptionally high red blood cell count and hemoglobin value was found (6,180,000 and 16.0 gr. Hg.) which would explain the high value of oxygen removal and large drop in arterial oxygen saturation during

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\* During the test this subject revealed a defective respiratory gas exchange. Clinical examination confirmed a pulmonary emphysema.

the exposure to 10.5% O<sub>2</sub> in N<sub>2</sub> for this subject. Between the two groups there was no significant difference.

f. Pulse Rate and Blood Pressure.

Pulse rate and blood pressure did not show definite differences between the two groups. Test-retest reliability for Group A was found to be  $r = .65$ ; for Group B,  $r = .85$ .

Figures 1 and 2 show in a typical way the course of the oxygen consumption and respiratory minute volume for a representative subject from the low and high ventilation groups. These permit visualization of the basis for differentiation of the two groups. Those with the low respiratory minute volume response accumulate the larger oxygen debt and vice versa.

## DISCUSSION

The average increase in respiratory minute volume during the first eleven minutes of exposure to 10.5% O<sub>2</sub> was 1.3 l./min. for the first trial and 1.96 l./min. for the second trial. These findings are comparable to values of Dripps and Comroe (11) who found an average increase of 1.3 l./min. for 6-8 minutes exposure to 10% O<sub>2</sub>. Reference to Table 3 shows that the respiratory minute volume was increased by slightly over 30% (approximately 2 liters/min. in the later time periods.) In both trials the respiration rate showed no significant variation from basic values in any time period. The significant increase in respiratory minute volume is therefore principally a function of increased tidal volume (Tables 2-A and 2-B). This is in accord with the findings of Smith (12) and in contrast to Margaria and Talenti (13) and Benzinger (14) who attribute the increase in respiratory minute volume to a combination of increased rate and increased tidal volume.

After having reached a stable level the average increase in pulse rate was 32% increase in the first trial and a 28% in the second trial. These values may be fitted to the curve of the effect of inhalation of various low oxygen mixtures on pulse rate published by Dripps and Comroe (Fig. 2, ref. (11)).

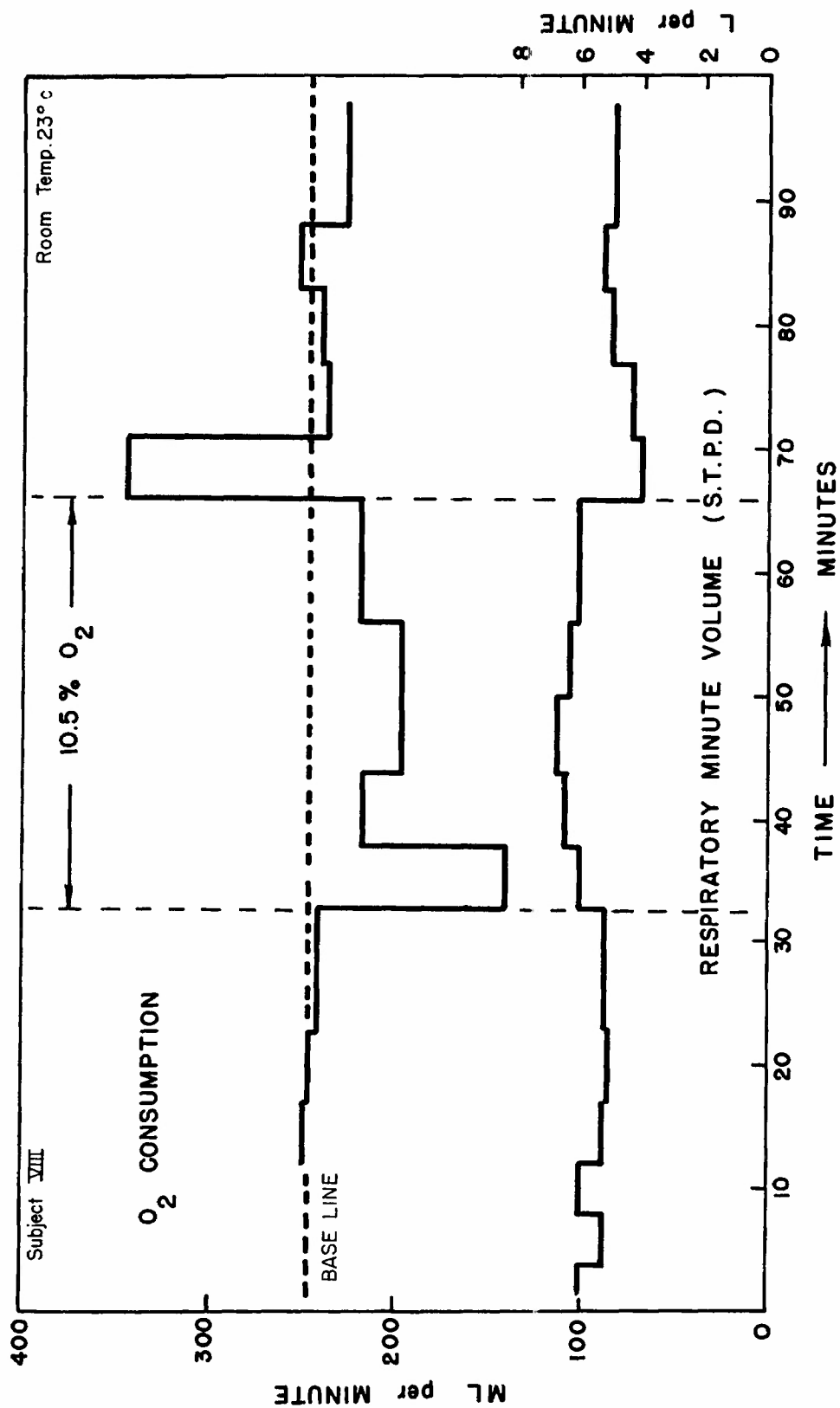


FIGURE I

Oxygen Consumption and Respiratory Minute Volume (S.T.P.D.) While Breathing Air, 10.5% O<sub>2</sub> in N<sub>2</sub> and again Air (each period 33 minutes).

Subject VIII. Decreased Oxygen Consumption throughout the Exposure to Low Oxygen. O<sub>2</sub> Debt = 1.56 liters at end of 33 minutes exposure.

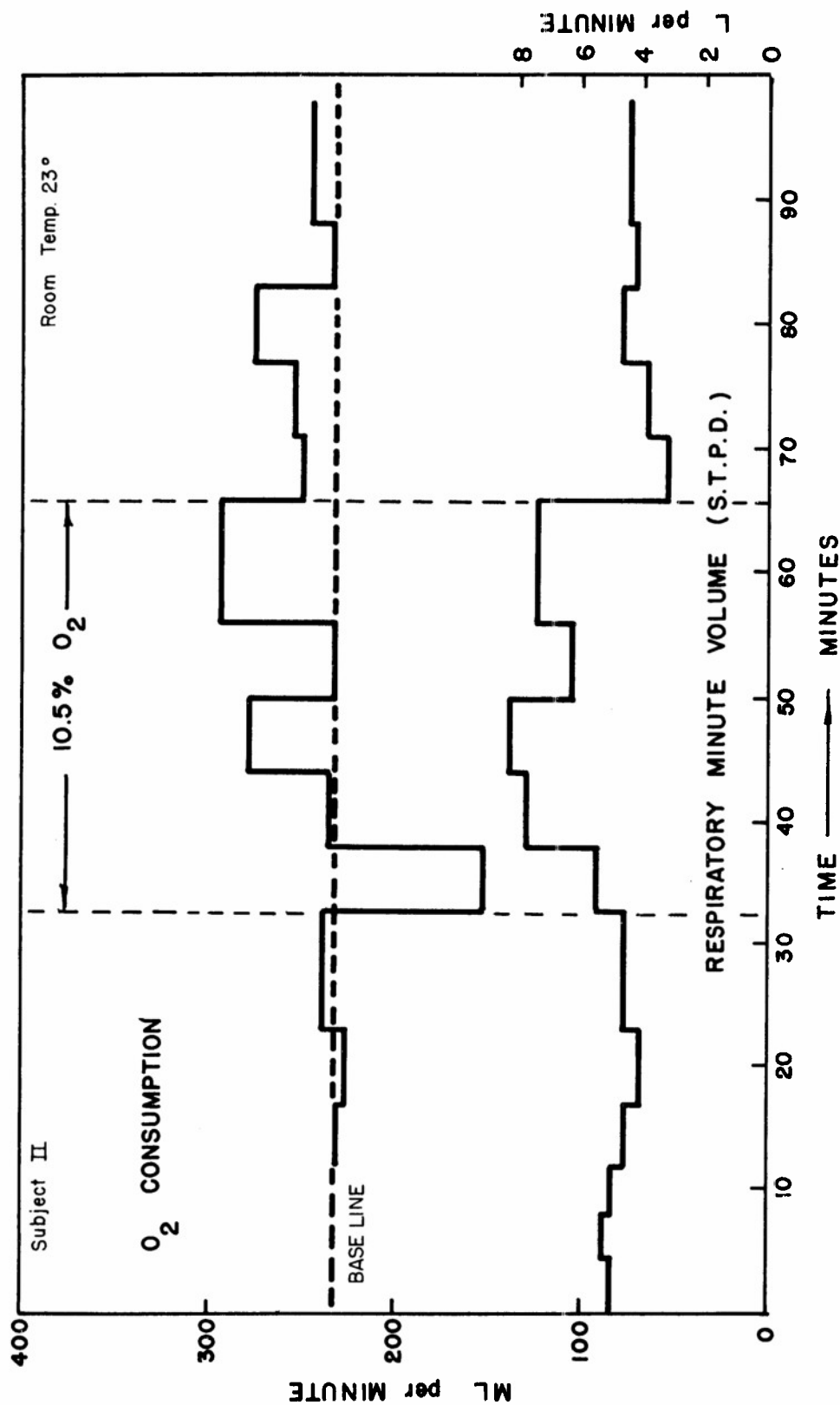


FIGURE II

Oxygen Consumption and Respiratory Minute Volume (S.T.P.D.) While Breathing Air, 10.5% O<sub>2</sub> in N<sub>2</sub> and again Air (each period 33 minutes).

Subject II. Initial Decrease followed by an Increase in Oxygen Consumption during Exposure to Low Oxygen. Oxygen Debt (0.397 liters) overcompensated during the exposure.

The oximeter readings of arterial blood saturation became stable at 24-25% below basic values from the 11th minute on in the first trial and at 23% below basic values during the period from the 18th minute on in the second trial. These are in close agreement with the comparable observations of Dripps and Comroe (11).

During a recovery period equal in length to the exposure, the expected counter movements of the observed respiratory and circulatory factors occurred at different time intervals. They were quite clear in the first trial but not so obvious in the second. Presumably those counter movements are due to the tonic activity of the chemoreceptors. Dripps and Comroe emphasize that the response of the circulatory system to low oxygen differed markedly from the respiratory response considering both their respective thresholds and the magnitudes of response. Here, at 10.5% O<sub>2</sub> in N<sub>2</sub> the magnitude of response expressed in percent of basic values is of the same order for both (approximately 30%, Table 3). These two functions show the stimulating effect of the low oxygen throughout the exposure period. On the other hand, the systolic blood pressure was first increased and later fell below basic values, both changes being significant. This depression of the systolic blood pressure in the later portion of the exposure may be a manifestation of hypoxic effect on the vasomotor centers.

In our studies, the exposure time of 33 minutes was long enough to approach a steady state. Stable levels in arterial oxygen saturation, respiratory minute volume and pulse rate were reached during this time. These values were reproducible. Average oxygen uptake was reduced 30% during the first five minutes and 6% in the time period from 5 to 11 minutes (Table 4). Converting this to absolute values, we have:

Mean basic oxygen uptake = 230 ml./min.

Then  $.30 \times 230 \times 5 = 345$  ml.

$.06 \times 230 \times 6 = 82.8$  ml.

Total 427.8

Thus, during the first 11 minutes of the exposure period, the average oxygen uptake for all subjects was 428 ml. less than the basic resting

oxygen uptake for the same period. Might this be attributed to changes in the arterial oxygen saturation? To answer this question Professor Rahn suggested the following calculation:

“Let A 1 = Arterial O<sub>2</sub> content breathing air ml./liter

A 2 = Arterial O<sub>2</sub> content breathing 10.5% O<sub>2</sub> ml./liter

Let V 1 = Venous O<sub>2</sub> content breathing air ml./liter

V 2 = Venous O<sub>2</sub> content breathing 10.5% O<sub>2</sub> ml./liter

Let X = the arterial blood volume

Y = the venous blood volume

X + Y = Total circulating blood volume

Then on going from air to 10.5% O<sub>2</sub> there would be a reduction in O<sub>2</sub> consumption equal to:

$$\text{Reduction in O}_2 \text{ uptake} = (A\ 1 - A\ 2) X + (V\ 1 - V\ 2) Y \quad (1)$$

If the A-V difference is unaltered on breathing 10.5% O<sub>2</sub> (which is not too likely, but it may not be altered much during rest) then the equation can be simplified as follows:

$$\text{Reduction in O}_2 \text{ uptake} = (A\ 1 - A\ 2) (X + Y) \quad (2)$$

Substituting our values of 25% drop in HbO<sub>2</sub> (Tables 2-A and 2-B) and converting to ml./liter while breathing 10.5% O<sub>2</sub> and assuming a total circulating blood volume of 7 liters, we then have (200-150) 7 = 350 cc.) In addition there must be a reduction in physically dissolved oxygen in tissue fluids. Using the mean capillary pO<sub>2</sub> as an index of mean tissue pO<sub>2</sub> tension, this value would not change more than 20 or 30 mm. Hg. upon going to 10.5% O<sub>2</sub> from air. Therefore, assuming a 30 mm. Hg. drop in this factor, with a solubility factor of 0.02 for O<sub>2</sub> in all tissues, this would yield an additional 70 cc. of O<sub>2</sub> by which the O<sub>2</sub> uptake would be reduced (calculated for 70 kg. man).”

These at best are only approximations but they come close to the average observed values (420 cc. calculated, 428 cc. observed). What does that mean? The average oxygen debt observed during exposure to 10.5% O<sub>2</sub> can be explained by the decreased O<sub>2</sub> uptake of the blood occurring on going from air to 10.5% O<sub>2</sub> (called blood factor hereafter). This oxygen debt, better called oxygen deficit, can be met by the oxygen reserves of the organism. Using the normal

values of  $O_2$  content for arterial and venous blood reported by Sunderman and Boerner (15), and assuming a total blood volume of 7 liters, the  $O_2$  content of the total blood would be 1137 cc. The myoglobin content estimated as hemoglobin (500 mgr. myoglobin per 100 gm. wet muscle cited by Sunderman and Boerner) would yield additional 188 cc.  $O_2$  for an average muscle weight of 28 kg. Total oxygen reserves would then be 1325 cc. This quantity of oxygen cannot entirely be utilized by the organism, but is certainly sufficient to meet the average oxygen deficit of 428 cc. This average oxygen deficit accepted during exposure to 10.5%  $O_2$  is different from the classical "oxygen debt" of A. V. Hill. There the energy requirement cannot be met by the concurrent oxidation energy productoin. From the 11th minute on, the respiratory and circulatory response to the low oxygen reach a constant level, and the average oxygen consumption does not show significant change. It is interesting to note that a 25% drop of the arterial oxygen saturation, which expresses the reduction of the oxygen uptake of the blood, is quantitatively compensated by a 30% increase in ventilation and a 28-30% increase in pulse rate. Increased oxygen supply to the alveoli and increased transportation of the blood are closely correlated to overcome the reduction in the  $O_2$  uptake of the blood imposed by the low oxygen tension in the inspired gas.

In Table 9, the oxygen debt accepted during the whole exposure to 10.5%  $O_2$  is listed for each subject. Most of the values are of such an order that it is possible to relate the oxygen debt to the reduction in  $O_2$  uptake of the blood occurring on going from air to low oxygen (blood factor). In four out of five subjects in the low ventilation group the  $O_2$  debt is over 1000 cc. The low ventilation group shows a greater oxygen removal from the inspired gas and in most cases a lower arterial oxygen saturation. If we use a 30% decrease in arterial oxygen saturation instead of 25%\* in the previous calculations the calculated oxygen uptake would be 490 ml. rather than 420 ml.

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\* Average drop of  $HbO_2$  was 31% in the first trial and 27% in the second trial for the low ventilation group at the end of 33 min. exposure to low  $O_2$ .

The better utilization of available oxygen by the low ventilation group still will not explain the large (over 1000 ml.) oxygen debts. The oxygen stores of the organism (1325 cc.), which can only be utilized to a certain degree, will not be sufficient to meet these larger oxygen debts (in one case, 1562 cc.). Consequently, it seems reasonable to assume that in four of the five subjects in this group a reduction of tissue oxidation must have occurred. Under similar conditions, exposure to 7.5%  $O_2$  for a period of 40 minutes, Jouck (5) found oxygen debts over 1000 cc. in the first minutes of the exposure to low oxygen followed by a compensatory increase in  $O_2$  uptake during the later time intervals on low oxygen. Most of our subjects from the low ventilation group accumulated their large oxygen deficits, over 1000 cc., during more extended time periods of the exposure to 10.5%  $O_2$  (Subjects VIII and XI throughout the 33 minutes of exposure and Subjects IX and X over 23 minutes). In the last time interval, 23-33 minutes, Subject IX reached the basic level (100.3%), whereas Subject X had a slightly increased  $O_2$  uptake of 110.4% compared with basic values.

These four subjects reach a stable level of ventilatory and circulatory response after the 11th minute but continue to accumulate an oxygen debt as exposure to low oxygen proceeds. They do not compensate for the reduced oxygen uptake by an adequate increase in ventilation or pulse rate. From the 11th minute of exposure the subjects of the high ventilation group reach the basic level in  $O_2$  uptake or show a compensatory increase in  $O_2$  uptake. When the values of oxygen uptake of the two groups from the 11th minute on are combined, the average does not demonstrate a difference from the basic oxygen uptake. In one case (Subject VIII) the oxygen debt was 1562 ml. and at the end of the recovery period after 33 minutes breathing air was still over 1000 ml. (Table 9). This same subject showed similar trends in a separate experiment breathing 15%  $O_2$ . While breathing 15%  $O_2$  for 33 minutes he accepted an oxygen debt of 930 ml. and at the end of a 33 minute recovery period breathing air it was still 430 ml. This indicates that the reduction of the oxidation is still effective in the recovery period on air following the exposure to low oxygen and that a shift to anaerobic energy yielding processes might have occurred.

We proceed to a clinical examination of each case listed in Table 8. Subjects I through III in the high ventilation group are all laboratory personnel. They show comparatively low values in maximum oxygen removal from inspired air, and a drop in oxygen saturation and oxygen debt, which is to be expected in association with a high ventilation response. Subject IV (laboratory personnel) has the lowest maximal ventilation in this group and a correspondingly large oxygen removal from inspired air and low oxygen saturation. These values place him at the borderline of the high and low ventilation group. They are explained by an exceptionally high red blood cell count and hemoglobin value (Table 10). The blood can therefore take up more oxygen from a given amount in the inspired gas. With this higher utilization of  $O_2$  associated with a moderate increase in ventilation, the need for oxygen is satisfied. He shows only a small sized oxygen debt, which could be correlated with the blood factor mentioned above. Subject V (laboratory personnel) shows two findings which, at a glance, cannot be correlated: (1) a very high ventilatory response, and (2) a large oxygen debt. On the other hand, his oxygen removal is the lowest measured from all subjects. This combination of findings would suggest a delay in the passage of  $O_2$  through the alveolar wall. This explanation is supported by a long time lag in the oximeter response in going from air to low oxygen and by a delay in nitrogen elimination while breathing 100% oxygen over a period of 33 minutes. The relatively large oxygen debt in this case must therefore be related to a delayed passage of oxygen through the alveolar wall rather than to a restriction of oxidation processes in the tissues. Subject VI has been an instructor at the Escape Training Tank for eighteen months. With his high ventilation response, he differs from the other four instructors belonging to the low ventilation group. The additional data correspond to the high ventilation. By observation of this man at work and by his own comment, it is apparent that he finds the work as an instructor more strenuous than the others. In skin diving, he cannot go deeper than 50 feet. Of the four instructors remaining, all in the low ventilation

group, Subject VII shows data as expected in the low ventilation group. He differs from the other three in his relatively small oxygen debt and his limited ability in skin diving (maximum depth 50 feet). Subjects VIII through X are recognized as being the most proficient skin divers being able to reach depths not attainable by other instructors (100 feet). All show a low respiratory response, a high oxygen removal from inspired gas and oxygen debts over 1000 cc. The drop in arterial oxygen saturation was comparatively large in Subject X. In the test with Subject IX the oximeter failed but the pretest had shown a large drop (32%). Subject VIII has a small drop in oxygen saturation (20%). In this case, where the highest oxygen debt was found, two mechanisms might be interfering with each other: higher utilization of available oxygen, and restriction of tissue oxidation. Subject XI, belonging to the laboratory personnel, was a qualified deep sea diver, in excellent physical condition. He showed a physiological response to low oxygen similar to those of the most efficient instructors of the Tank.

The data reveal two patterns of response to low oxygen:

1. A high ventilation response associated with comparatively low utilization by the blood of the oxygen in the inspired gas and a small oxygen debt (Subjects I, II, III, V and VI).
2. A low ventilation response associated with a higher degree of utilization by the blood of the oxygen in the inspired gas and a large oxygen debt (Subjects VIII, IX, X and XI).

Between these two patterns of response to low oxygen we should expect intermediate reactions\* associated with a higher degree of utilization of the oxygen in the inspired gas by the blood and a small oxygen debt. The small oxygen debt typical for the high ventilation response to low oxygen can be related to the reduced  $O_2$  uptake of the blood (referred to as blood factor of the  $O_2$  debt) on going from air to low oxygen. The large oxygen debt associated with the low ventilation response to low oxygen represents an oxygen debt in the classical sense. Reduction of tissue oxidation is likely to occur

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\* Subject IV and VII, who respectively have a moderate and a low ventilatory response.

under these conditions. Opitz (16) found reductions in  $O_2$  uptake in the latter part of exposures to low oxygen correlated with the onset of critical circulatory disturbances such as vagal bradycardia and increase in blood pressure. Opitz concluded that the circulatory disturbance rather than the decrease in  $O_2$  tension caused the reduction in  $O_2$  uptake. We did not observe circulatory symptoms of that kind. The decrease in systolic blood pressure occurring from the 23d to 33d minute of exposure to 10.5%  $O_2$  was shown by all subjects. It does not appear that circulatory disturbances would explain the larger  $O_2$  debt of our low ventilation group.

According to Loeschke (17),  $O_2$  uptake during exposure to low oxygen can be expected to increase more consistently at room temperatures above  $25^{\circ}C$ , and humidity of 70%. He concludes from these and other findings that the degree of peripheral vascularization influences the  $O_2$  uptake during exposure to low oxygen. In our experiments the room temperature was kept at  $23-25^{\circ}C$ , and the humidity around 40%, thereby eliminating variations in the degree of peripheral vascularization produced by different room temperatures.

It can therefore be assumed that the differences in respiratory minute volume, oxygen removal and  $O_2$  uptake during exposure to low oxygen represent real differences in the response of the subjects to lowered oxygen tension.

On the basis of the variable reaction of the organism to low oxygen as described, one can explain the contrary reports in the literature of decreased as well as increased oxygen uptake during exposure to low oxygen. For the first time an attempt was made to separate (1) the decreased  $O_2$  uptake related to decreased hemoglobin-oxygen saturation from (2) the oxygen debt accepted during the exposure to low oxygen. The reduced  $O_2$  uptake of the blood due to the diminished hemoglobin-oxygen saturation is expressed in the average initial decrease in  $O_2$  consumption which lasted in our experiments for 11 minutes, and in Jouck's similar experiments, in some cases, for 16 minutes. This initial decrease in  $O_2$  consumption should parallel the drop in hemoglobin-oxygen saturation which in turn parallels decrease in oxygen tension.

The low ventilation response associated with a large oxygen debt was shown for three instructors from the Tank and one subject considered to be in a well trained and good physical condition. What does the latter have in common with the other subjects? Physical exercise and skin diving impose a similar stress. The stress in exercise can be described as an exposure to metabolites, to low oxygen and high  $\text{CO}_2$ . Training is a state of acclimatization to these factors. The stress in skin diving with extended periods of breath-holding is exposure to low oxygen and high  $\text{CO}_2$ . Schneider and Karpovich (18) and Ranke (19) report that a trained athlete responds to exercise with a lower respiratory minute volume, a higher degree of utilization of  $\text{O}_2$  in the inspired air, and acceptance of a larger oxygen debt than the untrained. Karpovich and LeMaistre (20) express the opinion that the ability to accept an oxygen debt may be increased by training. Lower respiratory minute volume, a higher degree of utilization of  $\text{O}_2$  in the inspired gas and acceptance of a larger oxygen debt also are the features of the response to low oxygen of the most efficient skin divers and a trained subject. These facts suggest that there might be a state of acclimatization to the stress of skin diving (or breathholding) which is similar to the trained state (acclimatization to exercise).

#### SUMMARY

1. Exposure to 10.5%  $\text{O}_2$  in  $\text{N}_2$  for 33 minutes under basal conditions after a preliminary test period of 33 minutes breathing air in two trials on eleven subjects gave the following results:
  - a. Approximately 30% increase in respiratory minute volume associated with increased tidal volume.
  - b. No significant increase in respiration rate.
  - c. A 23-25% drop in arterial oxygen saturation after the 11th minute of the exposure.
  - d. An increase of the pulse rate which amounts to approximately 30% in the first trial and approximately 28% in the second trial.

2. The average oxygen consumption of eleven subjects during exposure to 10.5%  $O_2$  in  $N_2$  for 33 minutes decreased until the 11th minute of exposure and then stabilized at essentially a basic level. The following recovery period showed a significant increase of average  $O_2$  consumption only during the first five minutes.
3. The average  $CO_2$  excretion was significantly increased during the entire 33 minutes of exposure to 10.5%  $O_2$  in  $N_2$ . In the following recovery period on air the  $CO_2$  excretion was significantly decreased from the 11th through the 33d minute.
4. The respiratory quotient did not return to basic values during a 33 minute period of exposure to 10.5%  $O_2$  in  $N_2$  nor in the following 33 minute recovery period breathing air.
5. A group of subjects with a high ventilation response to 10.5%  $O_2$  in  $N_2$  was differentiated from a group with a low ventilation response. The low ventilation group shows a larger oxygen removal from the inspired gas and a larger oxygen debt. Most of the subjects of this group had a lower arterial oxygen saturation. An attempt was made to separate the decrease in  $O_2$  uptake due to the decrease in hemoglobin-oxygen saturation from the oxygen debt.

## REFERENCES

1. Gesell, R., Krueger, H., Nicolsen, H., Brassfield, Ch., and Pelecovich, M., Am.J.Physiol., 100, 202, 1932.
2. Benzinger, Th., Erg.Physiol., 40, 1, 1938.
3. Ruehl, A. and Kuehn, W., Z.Klin.Med., 125, 705, 1939.
4. Opitz, E. and Tillmann, O., Luftfahrtmed., 2, 94, 1938.
5. Jouck, K. Th., Luftfahrtmed. 9, 26, 1944.
6. Cook, S. F., National Research Council, Committee on Aviation Medicine, Report No. 405, Jan 1945.
7. Nims, L. F. and Olmsted, F., Report No. 47, Yale Aeromedical Research Unit, Sep 1945.
8. Rahn, H. and Otis, A. B., J.of Appl.Physiol., 1, 717, 1949.
9. Best, Ch. H. and Taylor, N. B., The Physiological Basis of Medical practice.
10. Handbook of Respiratory Data in Aviation, 1944, Committee on Aviation Medicine, OSD.
11. Dripps, R. D. and Comroe, J. H., Jr., Am.J.Physiol., 149, 277, 1947.
12. Smith, R. E., Naval Medical Research Institute, Project NM 001 003, X-313, Report No. 2, 3 May 1948.
13. Margaria and Talenti, Acta Aerophysiol., 1, 5, 1933.
14. Bensinger, Th., Luftfahrtmed. 2, 42, 1937.
15. Sunderman and Boerner, Normal Values in Clinical Medicine.
16. Opitz, E., Fiat Review of German Science, 58, 29, 1948.
17. Loeschke, H. H., Fiat Review of German Science, 58, 59, 1948.
18. Schneider, E. C. and Karpovich, P. V., Physiology of Muscular Activity, W.B.Saunders & Co., Philadelphia, 1948.
19. Ranke, O. F., Arbeits U. Wehrphysiologie, Quelle and Meyer, Leipzig, 1941.
20. Karpovich, R. V. and LaMaistre, H., Research Quarterly, 11, 40, 1944.

TABLE 1

## DESCRIPTION OF SUBJECTS

Subject	Age	Weight (lbs.)	Height (inches)	Height (cm.)	Surface Area (square meters)
<u>GROUP A</u>					
I	36	190	73	185	2.10
II	37	181	70½	179	2.01
III	39	152	66	168	1.76
IV	35	186	67	170	1.95
V	40	150	70	178	1.84
VI	27	194	69	175	2.04
<u>GROUP B</u>					
VII	37	165	68½	174	1.88
VIII	28	185	72	183	2.05
IX	29	180	70½	179	2.00
X	35	205	72	183	2.15
XI	27	170	70	178	1.95



TABLE 2-B

RESPIRATORY AND CIRCULATORY CHANGES PRODUCED BY BREATHING 10.5% OXYGEN OVER A PERIOD OF 33 MINUTES FOLLOWED BY A RECOVERY PERIOD IN AIR OF 33 MINUTES (11 SUBJECTS) (SECOND TRIAL)

	AIR (Mean Basic Values)	Differences between mean basic value and values obtained during exposure to: 10.5% O <sub>2</sub> in N <sub>2</sub>						Differences between mean basic value and values obtained during recovery period (AIR)					
		11'45"- 33'15"	0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"	0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"	
A Respiratory Min. Volume liters/min. (BTPS)	Time												
	Mean Sigma P	5.8 ±.71	+1.91 1.26 .001	+2.00 1.13 .001	+2.19 1.11 .001	+2.29 1.25 .001	+2.07 1.13 .001	+2.26 1.70 .7	-.14 1.63 .8	+2.06 1.13 .9	-.31 1.18 .5	-.02 .28 .9	
B Respirations per min.	Mean Sigma P	11.4 ±1.84	+.14 1.24 .8	-.17 1.29 .7	+.07 2.64 .9	+2.06 2.75 .9	+.85 3.01 .4	-.6 4.06 .7	-1.18 2.73 .2	-.45 2.06 .5	-.3 2.31 .7	-.16 1.46 .8	
C Tidal Volume cc.	Mean Sigma P	544.6 ±81.6	+151.09 60.35 .001	+162.73 76.45 .001	+202.91 179.69 .01	+175.64 122.12 .01	+142.00 194.33 .05	+112.09 200.50 .2	+78.82 216.25 .3	+30.09 153.04 .6	-5.00 120.44 .9	+12.55 120.29 .8	
D % O <sub>2</sub> Satu- ration (Oximeter)	Mean Sigma P	95.6 ±.57	-14.10 4.50 .001	-18.4 4.63 .001	-20.6 4.57 .001	-23.1 5.96 .001	-23.5 7.2 .001	-3.27 4.61 .05	+.27 2.29 .8	+1.64 .91 .001	+1.45 1.62 .2	+1.18 .88 .01	
E Pulse/min.	Mean Sigma P	59.2 ±10.0	+7.91 3.96 .001	+13.18 5.94 .001	+13.73 10.00 .01	+15.91 8.62 .001	+17.18 9.53 .001	+3.91 7.86 .2	-2.55 6.03 .2	-2.55 3.73 .1	-2.45 6.10 .3	-1.18 4.02 .4	
F Blood Pressure	Mean Sigma P	108.18 ±7.37	+7.82 3.24 .001	+6.55 4.07 .001	+3.91 8.46 .2	+2.18 8.11 .5	-5.73 7.13 .02	-6.91 9.86 .001	-4.27 7.19 .1	-3.91 10.16 .3	-3.27 7.10 .2	-1.64 4.44 .3	

TABLE 3

RESPIRATORY MINUTE VOLUME AND PULSE RATE WHILE BREATHING  
AIR (BASIC VALUES), 10.5% O<sub>2</sub>, AND AIR, EACH FOR A PERIOD  
OF 33 MINUTES (IN % OF BASIC VALUES)

(11 SUBJECTS)

	AIR (Mean Basic Values)	10.5% O <sub>2</sub> in N <sub>2</sub>						Recovery Period (AIR)					
		0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"	0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"		
FIRST TRIAL	Time	11'45"- 33'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"	0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"		
Resp. Min. Vol. in % of Basic Values	Mean Sigma	6.0=100%	132.4 18.38	139.7 22.77	133.1 13.79	139.8 18.90	99.9 32.06	92.6 20.37	100.2 13.99	103.0 16.08	97.5 10.24		
Pulse Rate in % of Basic Values	Mean. Sigma	60.7=100%	131.3 12.01	130.8 13.68	132.1 14.62	133.2 17.13	114.8 25.27	93.6 6.48	94.2 5.64	94.7 5.54	98.0 6.58		
SECOND TRIAL	Mean Sigma	5.8=100%	133.79 20.61	137.03 18.58	139.69 20.41	138.04 17.79	106.25 29.87	98.66 27.01	101.95 19.78	95.85 18.78	99.87 4.81		
Pulse Rate in % of Basic Values	Mean Sigma	59.2=100%	121.64 8.40	123.36 16.42	127.18 14.34	129.36 15.83	106.45 14.54	95.91 11.76	95.64 6.75	94.18 13.40	96.82 3.01		

TABLE 4

OXYGEN CONSUMPTION AND CO<sub>2</sub> EXCRETION BREATHING AIR,  
10.5% O<sub>2</sub> AND AIR, EACH FOR A PERIOD OF 33 MINUTES  
(11 SUBJECTS) (SECOND TRIAL)

	AIR (Mean Basic Values)	Mean Values during exposure to: 10.5% O <sub>2</sub> in N <sub>2</sub>						Mean Values during recovery period (AIR)					
		Time	11'45"- 33'15"	0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"	0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"
(OBSERVED VALUES)													
O <sub>2</sub> Con. cc./min.	Mean	232.19	163.05	217.7	227.27	226.05	243.12	338.47	250.34	241.06	236.35	233.37	
	Sigma *P	16.71 -	36.52 .001	21.64 .05	36.35 .6	27.47 .5	37.64 .3	107.32 .001	57.07 .3	38.83 .4	28.40 .6	28.01 .9	
CO <sub>2</sub> Excr. cc./min.	Mean	194.14	239.00	232.82	240.51	227.87	224.86	168.48	171.86	175.35	176.87	181.42	
	Sigma *P	16.64 -	30.19 .001	34.87 .001	37.45 .001	20.43 .001	31.60 .001	51.74 .1	39.41 .1	19.07 .02	22.39 .05	12.78 .05	
(RELATIVE VALUES)													
O <sub>2</sub> Con. in % of Basic Values	Mean	100.	69.88	93.93	98.01	96.47	104.34	153.7	111.05	106.90	104.12	103.1	
	Sigma *P	- -	13.04 .001	6.08 .001	12.28 .5	10.05 .2	12.06 .2	34.73 .001	12.99 .01	7.37 .001	4.10 .001	6.27 .1	
CO <sub>2</sub> Excr. in % of Basic Values	Mean	100.	123.87	119.23	124.00	117.75	115.65	84.53	88.97	90.71	91.75	93.94	
	Sigma *P	- -	19.09 .001	14.81 .001	15.48 .001	10.32 .001	11.89 .001	27.58 .05	21.74 .1	10.75 .001	14.44 .05	8.86 .02	

\* Significance of difference between basic values and values  
obtained during exposure to 10.5% O<sub>2</sub> and the recovery period  
on air.

TABLE 5  
RESPIRATORY QUOTIENT WHILE BREATHING AIR,  
10.5% O<sub>2</sub> AND AIR, EACH FOR A PERIOD OF 33  
MINUTES (11 SUBJECTS) (SECOND TRIAL)

	AIR (Mean Basic Values)	10.5% O <sub>2</sub> in N <sub>2</sub>								Recovery Period (AIR)			
		0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"	0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"		
Time	11'45"- 33'15"												
M	.84	1.51	1.06	1.07	.99	.93	.48	.66	.71	.74	.77		
Sigma	.05	.27	.09	.09	.07	.04	.14	.11	.12	.08	.08		
*P	-	.001	.001	.001	.001	.001	.001	.001	.01	.01	.05		

\* Significance of difference between basic values and values obtained during exposure to 10.5% O<sub>2</sub> and the recovery period on air.

TABLE 6

AVERAGE ALVEOLAR  $p\text{CO}_2$  AND  $p\text{O}_2$  AFTER BREATHING AIR,  
 10.5%  $\text{O}_2$ , AND AIR OVER A PERIOD OF 33 MINUTES  
 (SAMPLE TAKEN AT 33 MINUTES EXPRESSED IN mm.Hg.)  
 (11 SUBJECTS)

	AIR (Basic Values)	10.5% $\text{O}_2$ in $\text{N}_2$	AIR Recovery Period
(FIRST TRIAL)			
Alveolar $p\text{CO}_2$			
M	37.50	31.83	35.60
Sigma	2.52	3.22	2.99
Alveolar $p\text{O}_2$			
M	106.99	43.47	107.55
Sigma	4.34	5.52	6.25
(SECOND TRIAL)			
Alveolar $p\text{CO}_2$			
M	37.8	32.01	36.1
Sigma	2.0	2.8	2.9
Alveolar $p\text{O}_2$			
M	108.7	45.2	110.0
Sigma	2.8	4.3	4.53

TABLE 7

RESPIRATORY MINUTE VOLUME WHILE BREATHING AIR (BASIC VALUES), 10.5% O<sub>2</sub> IN N<sub>2</sub> AND AGAIN AIR, EACH FOR A PERIOD OF 33 MINUTES (IN % OF BASIC VALUES) FOR TWO GROUPS OF SUBJECTS

	AIR (Mean Basic Values)	10.5% O <sub>2</sub> in N <sub>2</sub>						Recovery Period (AIR)					
		Time	11'45"- 33'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"	0'15"- 5'15"	5'30"- 11'30"	11'45"- 17'45"	18-23'	23'15"- 33'15"	
Resp.Min. Vol. GROUP A-FIRST TRIAL		Aver. Sigma	5.8=100% .82	126.9 16.1	149.7 24.1	142.2 10.3	154.9 12.3	99.0 26.7	91.2 25.0	94.5 20.3	106.8 19.8	98.5 13.4	
GROUP A-SECOND TRIAL		Aver. Sigma *P	5.7=100% .21 .8	143.7 22.11 .2	149.6 16.4 .9	156.6 11.4 .1	149.5 16.7 .6	117.3 34.4 .4	109.0 32.9 .4	111.5 21.3 .3	100.3 21.6 .7	100.1 4.7 .9	
GROUP B-FIRST TRIAL		Aver. Sigma	6.04=100% .68	119.7 3.25	125.0 11.3	123.2 10.6	123.7 7.6	102.5 30.0	96.0 8.9	97.2 7.2	97.1 7.1	98.2 5.3	
GROUP B-SECOND TRIAL		Aver. Sigma *P	5.8=100% .82 .3	121.9 10.6 .7	122.0 5.6 .7	119.4 2.5 .5	124.3 5.6 .9	93.0 16.6 .5	86.2 5.4 .05	90.5 9.6 .3	90.6 14.4 .4	99.6 5.4 .7	
Compari-FIRST son of TRIAL		**P	.7	.4	.1	.02	.01	.9	.8	.9	.4	.9	
GROUPS SECOND A and B TRIAL		**P	.9	.1	.01	.001	.001	.3	.2	.1	.5	.3	

\* Significance of difference between first and second trials of each group.

\*\* Significance of difference between the two separate groups.

TABLE 8

BASIS FOR THE DIFFERENTIATION OF TWO GROUPS  
REGARDING THEIR RESPONSE TO LOW OXYGEN

	1	2	3	4
SECOND TRIAL	Maximum Increase in Ventilation While Breathing 10.5% O <sub>2</sub> in N <sub>2</sub> Over a Period of 33 Minutes Compared with Basic Values on Air=100%	Maximum O <sub>2</sub> Removal from Inspired Gas While Breathing 10.5% O <sub>2</sub> in N <sub>2</sub> Over a Period of 33 Minutes (in % O <sub>2</sub> )	Maximum Drop in Arterial O <sub>2</sub> Saturation While Breathing 10.5% O <sub>2</sub> in N <sub>2</sub> Over a Period of 33 Minutes (% Hb O <sub>2</sub> )*	O <sub>2</sub> Debt Accepted During 33 Minutes of Exposure to 10.5% O <sub>2</sub> in N <sub>2</sub> (ml.)
GROUP A				
Subject I	160	-3.43	-21	-395
II	178	-3.96	-23	-397
III	165	-3.87	-22	-204
IV	161	-4.10	-35	-395
V	184	-3.08	-24	-796
VI	154	-3.71	-20	-627
Mean	163.67	-3.74	-24.17	-469
Sigma	.113	.4298	.0781	162.4
P	15.03	.451	5.49	.01
GROUP B				
Subject VII	129	-4.22	-36	-503
VIII	129	-4.53	-20	-1562
IX	135	-4.40	-	-1035
X	120	-4.08	-30	-1035
XI	128	-4.42	-31	-1146
Mean	128.20	-4.33	-29.25	-1056.2
Sigma	.116	.1597	.0574	337.9
P	.025	.025	.7	.01

\* Mean values of 5 readings at minute intervals.

Values listed in columns 1, 2 and 3 are selected as the most significant in one of five time periods.

TABLE 9

OXYGEN DEBT AND COMPENSATORY UPTAKE  
RESULTING FROM EXPOSURE TO 10.5% O<sub>2</sub>

	10.5% O <sub>2</sub> Exposure		Recovery Period Breathing Air	Final O <sub>2</sub> Balance (ml.)
	O <sub>2</sub> Debt (ml.)	O <sub>2</sub> Balance at End of Exposure (ml.)	O <sub>2</sub> Uptake Above Basic Values (ml.)	
GROUP A	-395	39	2246	2285
	-397	473	619	1092
	-204	-184	755	571
	-395	-103	1199	1096
	-796	-796	856	60*
	-627	-207	701	494
Mean	-469.00	-129.67	1062.67	933.90
Sigma	162.40	375.34	560.33	703.05
P	.01	.01	.8	.1
GROUP B	-503	-495	479	-16
	-1562	-1562	489	-1073
	-1035	-782	1421	639
	-1035	-1027	1085	58
	-1146	-1146	1326	180
Mean	-1056.20	-1002.40	960.00	-42.40
Sigma	337.88	357.88	403.81	563.32
P	.01	.01	.8	.1

\* Exclusion of Subject 5 in Group A (case of pulmonary emphysema) would make the final O<sub>2</sub> balance in Group A significantly different from Group B. (Group A: M = 1107; S.D. = 641.5; P = .05)

TABLE 10  
BLOOD DATA FOR 11 SUBJECTS

Subject	R.B.C.	Hgb. (Grams)	Hematocrit (%)	
			20'	30'
I	5.440	15.5	47	46
II	5.130	14.5	42	40
III	5.380	15.5	45	44
IV	6.180	16.0	48	45
V	5.010	15.0	41	40
VI	4.910	14.5	43	41
VII	5.050	15.5	48	46
VIII	5.230	14.5	42	39
IX	4.810	15.0	47	45
X	5.860	16.0	47	45
XI	5.540	15.5	50	48

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